IN THE TITLE:

Please change the title to read:

METHOD AND DEVICE FOR USING A MULTI-CHANNEL MEASUREMENT SIGNAL IN SOURCE MODELLING

IN THE SPECIFICATION:

Page 2, 1st full paragraph

Conventional minimum norm estimates involve inherent problems such as slowness of calculation and susceptibility to noise. For example, in the case of an L2 norm, one needs an inverse matrix of matrix G, whose element (i, j) contains the inner product of the ~~switching~~ lead fields of the ith and jth measurement sensor, so one must calculate these inner products for each pair of sensors. The ~~switching~~ lead field is so determined that the signal measured by a sensor is the projection of the current distribution for the ~~switching~~ lead field of the sensor in question. The noise problems are due to the fact that matrix G calculated for the sensors is susceptible to noise, so in the calculation of its inverse matrix, regularisation is needed in the practical situations.

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Regularisation methods, such as the ~~break-off~~ truncation regularisation of the singular value decomposition, usually are non-intuitive, and usually also to be solved for each case specifically. A regularisation of the wrong type may lead to an erroneous modelling result.

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The basic idea of the invention is that because the computation of the inner products of the sensor fields is hard and difficult using a conventional set of sensors, it is worth using a special set of sensors, whose ~~switching~~ lead fields are orthogonal and, if possible, to be analytically computed. In principle, this can be implemented by a suitable physical set of sensors. As a suitable physical set of sensors is, however, often quite difficult to manufacture, it is, in most of the cases, advantageous to use virtual sensors computationally generated from a conventional set of sensors, i.e. the measurement signals are converted into other ones by a suitable conversion so that they correspond to the signals that the virtual measurement device

would have measured. At the same time, it is possible, if necessary, to eliminate the signals associated with external interference. This conversion has been described e.g. in patent application FI20030392, which is incorporated herein by reference. After the conversion, the source modelling is performed in an optimal manner using the basis vector components of the signal space instead of the actual measurement signals. One substantial feature of the invention is that after the conversion, the source model need not be any more regularised.

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According to the invention, a multi-channel measurement signal corresponding to each measurement sensor is converted into the signals of a predetermined set of virtual sensors, and the current distribution of the object being examined is determined by depth r from the signals of the set of virtual sensors in a beforehand selected orthonormal function basis. In that case, the estimation of a current distribution is fast and robust. Further, to achieve the set of signals corresponding to the set of virtual sensors, a multi-pole development is calculated from a multi-channel measurement signal. A multi-pole development can be calculated in two ways: by taking into account the magnetic fields emitted by sources outside the object being measured, or by ignoring them.

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Advantageously, as the orthonormal function basis, a basis with the following form is selected:

$$\cancel{\overset{\rho}{J}(\overset{\rho}{r}) = \sum_{l=0}^{L}\sum_{m=-l}^{l} c_{lm} f(r) \overset{\rho}{X}lm(\theta,\varphi),}$$

$$\underline{\vec{J}(\vec{r}) = \sum_{l=0}^{L}\sum_{m=-l}^{l} c_{lm} f_l(r) \vec{X}lm(\theta,\varphi),}$$

wherein ~~f (r)~~ $\underline{f_l(r)}$ is a radial function to be freely selected and $\cancel{\overset{\mu}{X}_{lm}(\theta,\varphi)}$ $\underline{\vec{X}_{lm}(\theta,\varphi)}$ is

so-called vector spherical harmonic. In that case, it is possible to place the function basis into a current distribution equation, and the coefficients of the current distribution are analytically solved based on the equation:

$$\cancel{C_{lm} = \hat{\gamma}_l M_{lm} \left[\int_0^R r^1 f(r) dr \right]^{-1}},$$

$$\underline{C_{lm} = \hat{\gamma}_l M_{lm} \left[\int_0^R r^{l+2} f_l(r) dr \right]^{-1},}$$

wherein $\cancel{\gamma_l}$ $\underline{\hat{\gamma}_l}$ is a constant associated with order 1 and R is the radius of the sphere to be examined. Advantageously, function $\cancel{f(r)}$ $\underline{f_l(r)}$ is used to adjust the depth weighing of a current distribution model.

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According to the invention, the processing means include a conversion module for converting a multi-channel measurement signal corresponding to each measurement sensor into the signal of a predetermined set of virtual sensors; and calculation means for determining the current distribution of an object being examined or for calculating by depth r from the signals of the set of virtual sensors in a beforehand selected orthonormal function basis. In one embodiment, the calculation means are arranged to calculate a multi-pole ~~development~~ <u>expansion</u> from a multi-channel measurement signal.

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In the following section, the mathematical background and grounds of the invention are described. When the magnetic fields are converted into coefficients $M_{lm} = a_{lm} + ib_{lm}$ associated with the basic solution $r^{-(l+1)}Ylm(\theta,\varphi)$ of the Laplace equation, wherein i is an

imaginary unit, they can be expressed by means of the current distribution $\cancel{\overset{\rho}{J}(\overset{\rho}{r})}$ $\underline{\vec{J}(\vec{r})}$ in spherical coordinates (r, θ, ρ), whereby they are of the form:

$$\cancel{M_{lm} = \gamma_1 \int_V r^l \overset{\rho}{X}lm(\theta,\varphi) \bullet \overset{\rho}{J}(\overset{\rho}{r})dv} \qquad \cancel{(1)},$$

$$\underline{M_{lm} = \gamma_l \int_V r^l \vec{X}lm(\theta,\varphi) \bullet \vec{J}(\vec{r})dv} \qquad \underline{(1),}$$

wherein the integration is performed over the volume being examined, γ_l is a constant associated with order 1 and $\cancel{\overset{\rho}{X}lm(\theta,\varphi)}$ $\underline{\vec{X}lm(\theta,\varphi)}$ is so-called vector spherical harmonic.

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This form ~~is apparent~~ can be derived e. g. from publication "Multipole expansions of electromagnetic fields using Debye potentials", C. G. Gray, American Journal of Physics, Vol. 46, pp. 169-179, 1978. The expression mentioned above is of the ~~switching~~ lead field form, wherein the switching field of the multi-pole coefficient M_{lm} is of the form:

$$\cancel{\overset{\rho}{L}_{lm}(\overset{\rho}{r}) + r^1 \overset{\rho}{X}_{lm}(\theta,\varphi)} \qquad \cancel{(2)}.$$

$$\underline{\vec{L}_{lm}(\vec{r}) + r^1 \vec{X}_{lm}(\theta,\varphi)} \qquad \underline{(2).}$$

On the other hand, the vector spherical harmonics form by depth r an orthonormal basis, so with the depth in question, the current distribution can be presented in the function basis in question:

$$\cancel{\overset{\rho}{J}(\overset{\rho}{r}) = \sum_{l=0}^{L}\sum_{m=-1}^{l} c_{lm} f_1(r) \overset{\rho}{X}lm(\theta,\varphi),} \qquad \cancel{(3)}.$$

$$\underline{\vec{J}(\vec{r}) = \sum_{l=0}^{L}\sum_{m=-l}^{l} c_{lm} f_l(r) \vec{X}lm(\theta,\varphi),} \qquad \underline{(3).}$$

wherein $f_l(r)$ is some radical function.

When as the volume to be examined, spherical volume is selected, by placing the previous expression into the equation (1), the coefficients of the current distribution can be analytically solved:

$$\cancel{C_{lm} = \hat{\gamma}_l M_{lm} \left[\int_0^R r^l f(r) dr \right]^{-1},} \qquad \cancel{(4),}$$

$$\underline{C_{lm} = \hat{\gamma}_l M_{lm} \left[\int_0^R r^{l+2} f_l(r) dr \right]^{-1},} \qquad \underline{(4).}$$

wherein $\hat{\gamma}_l$ is a constant associated with order 1 and R is the radius of the sphere to be examined. The previous equation (4) indicates that the coefficients of a current distribution model presented in an orthonormal basis can be solved based on coefficients M_{lm} in a completely trivial manner using analytical expressions without any kind of regularisation. This is computationally very fast and numerically stabile. Function $\cancel{f(r)}$ $\underline{f_l(r)}$ is freely selectable, and can be used to adjust the depth weighing of a current distribution model.